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Flood risk assessment as an integral part of urban planning

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INTRODUCTION

This poster presents a software framework that integrates flood risk assessment using the 1D-2D hydraulic model MIKE FLOOD and urban development modelling using the DAnCE4Water platform. This framework allows for the systematic evaluation of flood adaptation strategies given a variety of future scenarios for urban development and climate change. Adaptation strategies can thus be tested with respect to their robustness towards different futures.

The framework aims to bridge the gaps between different professions involved in the urban planning process and therefore allows for the consideration of traditional flood adaptation strategies focusing on modifications of the urban water infrastructure such as pipes or dikes, just as well as decentralised water management and urban planning policies aimed towards a water sensitive city development. Reductions in flood risk are evaluated in a cost-benefit assessment which permits to compare investment cost against reductions in flood risk as well as added benefits such as reductions in drinking water consumption.

METHODS

We tested various combinations of flood adaptation ***strategies*** for different ***scenarios***, manifested in varying drivers of flood risk, such as population growth or climate change. A combination of a certain adaptation strategy and a specific scenario is called a ***pathway***.

In a 300 ha case study catchment in Melbourne, Australia we evaluated strategies over a planning horizon of 50 years. Urban development was simulated for each pathway using DAnCE4Water [1]. A planning horizon of 50 years was considered and flood risk was assessed every 10 years along the pathway by transferring the new urban layout into the 1D-2D hydraulic model MIKE FLOOD. This process is illustrated in Figure 1.

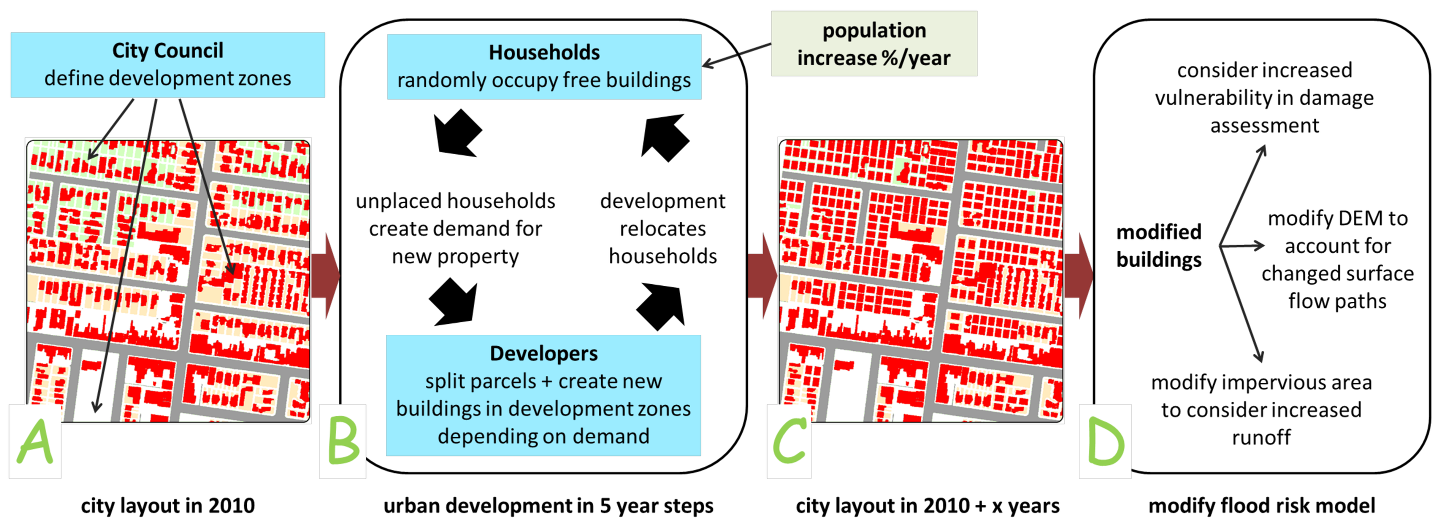


Figure 1 – Schematic illustration of the urban development model and its linkage to the hydraulic model.

Urban development was modelled as interaction between the key actors city council, developers and households. City councils define different zones for development (white, green and orange in subfigure A), developers split parcels of sufficient size and develop new buildings on these depending on housing demand and households appear as a result of population growth and move into new buildings. The result was a more dense urban layout illustrated in subfigure C.
The new building set is then transferred into the hydraulic model (subfigure D) to assess flood risk.

Scenarios define potential futures. We considered (in all combinations):

- increase in rain intensity of 0, 0.5 or 1% per year due to climate change,
- population growth of 0.4, 0.8 or 1.2% per year.

Increases in rain intensity and population growth lead to a continuous increase of flood risk in the catchment over the planning horizon, as a result of greater flood hazard and increased vulnerability.

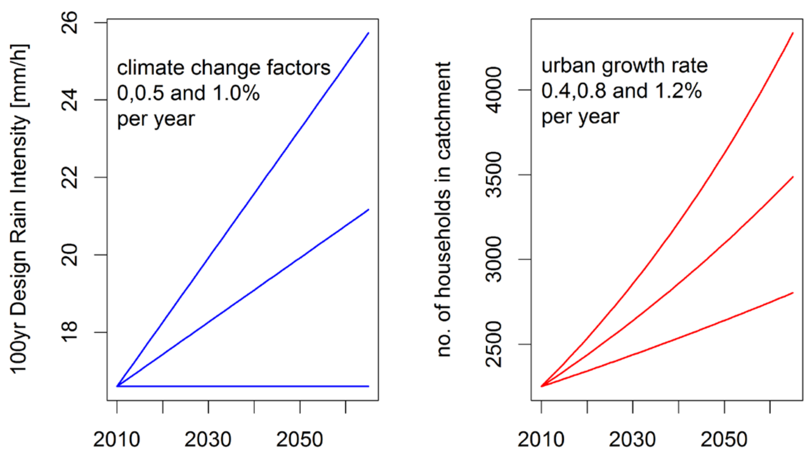
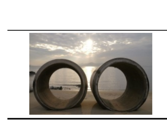


Figure 2 – Change of 100yr design rain intensity and number of households in the catchment over the planning horizon in different scenarios.

Flood adaptation was considered in the simulations either by modifying the urban development through different zoning or by directly implementing changed water infrastructure in the hydraulic model. We have considered the flood adaptation strategies shown in Table 1 (in all combinations).

Table 1 – Flood adaptation strategies considered in case study

	Adaptation Strategy	Description	Implementation in Simulation Setup
	Master Planning	urban sprawl vs. compact development	modify zoning and building types developed in DAnCE4Water
	Flood Zoning	uncontrolled development vs. gradual buyback of properties flooded at least once in 100 years	modify zoning in DAnCE4Water
	Rainwater Harvesting (RWHT)	large scale implementation of rainwater harvesting tanks in the catchment at rates of 0, 1, 3 and 5% per year	randomly assign RWHT to buildings in DAnCE4Water, transfer to MIKE Flood as change in impervious area
	Pipe Increase	increase pipe capacity so flooding occurs at most once in 10 years	use modified pipe network for simulations in MIKE Flood

Cost benefit assessment: We compared accumulated investment and operation expenses over the planning horizon against benefits from reduced flood risk and smaller drinking water consumption. As flood risk is not stationary, reduced flood risk must be derived by comparing against a reference without adaptation for the exact same scenario and net present value (NPV) must be computed separately for each scenario [2].

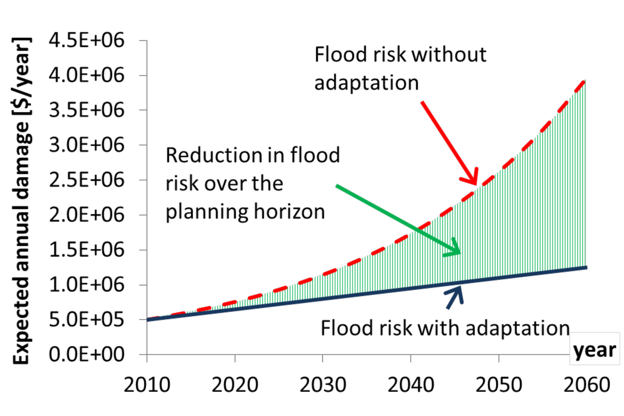


Figure 3 – Reduction in flood risk for non-stationary climate and urban layout. Each scenario requires a separate assessment.

RESULTS

A total of 32 potential combinations of adaptation options was simulated for 9 scenarios each, leading to a total of 288 pathways. Along each pathway, flood risk was assessed every 10 years, by considering 7 design rain storms with return periods from 1 to 100 years, leading to a total of 12,096 1D-2D hydraulic simulations in MIKE FLOOD. Figure 4 highlights flood risk for selected strategies, while Table 2 illustrates net present values derived for different adaptation options..

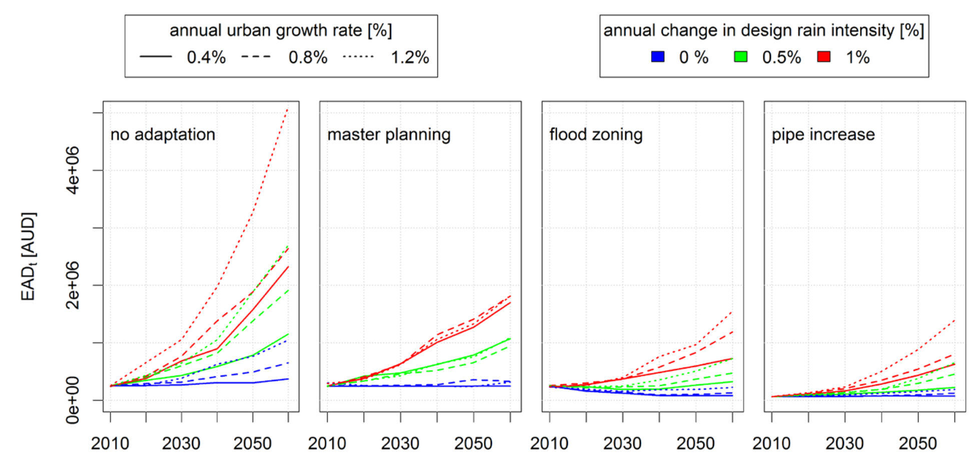


Figure 4 – Development of flood risk expressed as expected annual damage over the planning horizon for selected adaptation strategies.

Increasing rain intensities lead to increasing flood hazard and thus increased risk. Population growth increases vulnerability and thus flood risk. All shown adaptation strategies are efficient in reducing flood risk.

Table 2 – Net present value (NPV in 10^6 AUD) for selected combinations of flood adaptation options. Shown are the mean and maximum values over the 9 considered scenarios.
Observe the often large differences between average NPV over all scenarios and maximal NPV derived for a single scenario, the systematically negative values for adaptation involving flood zoning and that the implementation of RWHT tends to lower NPV if combined with other adaptation options.

Flood zoning	**NO**				**YES**			
Pipe increase	**NO**		**YES**		**NO**		**YES**	
Master plan	**Sprawl**							
RWHT rate	**0%**	**3%**	**0%**	**3%**	**0%**	**3%**	**0%**	**3%**
Mean NPV	0	-0.9	-9.8	-12.5	-90.1	-89.7	-115.8	-116.1
Max NPV	0	5.2	9.1	7.1	-71.5	-76.2	-93.9	-99.5
Master plan	**Compact**							
Mean NPV	11	9.2	-7.5	-10.2	-89.6	-89.0	-116.2	-116.5
Max NPV	29	29.4	16.2	14.2	-66.8	-68.6	-91.2	-93.9

DISCUSSION

Robust Strategies: Figure 4 suggests that flood risk in the catchment is very much increased by changing rain intensities and population growth. Master planning was the most efficient strategy to mitigate changes in flood risk, because it did not require additional investment cost. Flood zoning reduced flood risk, but was applied to too large an area and was too costly as a result. Several strategies scored clearly positive NPV in some scenarios, while not being efficient on average over all scenarios. Increasing pipe capacity to handle a fixed design event would, for example, not be robust towards a variety of futures.

Uncertainty: Our simulation setup provides a means to test the robustness of flood adaptation towards a variety of futures and thus goes one step further than traditional, projection-based planning approaches. However, it is limited to the consideration of futures that can be envisioned by the stakeholders, and we cannot currently handle uncertainty that we are not aware of or that we cannot quantify [3]. In addition, the simulation setup as such is subject to a number of uncertainties such as assumptions on flood damages for buildings or an assumed on-going evolution of the city through parcel splitting.

CONCLUSIONS

We have successfully applied a simulation setup coupling the urban development modelling platform DAnCE4Water and the 1D-2D hydraulic modelling package MIKE FLOOD to systematically test flood adaptation options for a variety of climate and urban development scenarios. We draw the following conclusions:

- flood risk is very much subject to changes in climate **AND** urban development,
- an urban planning policy proved to be the most efficient flood adaptation strategy, because reductions in flood risk could be obtained as a side-effect of urban planning without additional investment cost,
- the efficiency of flood adaptation strategies depends on which climate and urban development scenarios are considered and which other strategies are implemented,
- flood adaptation strategies should be designed in a way which can be flexibly adapted in the future. This result is in line with the findings of previous studies [1].

References: [1] Urich, C; Rauch, W (2014) Exploring critical pathways for urban water management to identify robust strategies under deep uncertainties, Water Research, 66C, 374-389.
[2] Zhou, Q; Mikkelsen, PS; Halsnæs, K; Arnbjerg-Nielsen, K (2012) Framework for economic pluvial flood risk assessment considering climate change effects and adaptation benefits, Journal of Hydrology, 414-415, 539–549.
[3] Walker, WE; Lempert, R; Kwakkel, J (2013) Deep Uncertainty, Encyclopedia of Operational Research and Management Science, 395-402.

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